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Fundamental plane of groups and clusters of galaxies: distances and peculiar velocities of superclusters of galaxies on small scales

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Abstract. We have studied the relationships between the basic properties of 172 groups and clusters of galaxies based on archival data from the SDSS, 2MASX, and NED catalogs. The measured parameters ($\log R_e$, $\langle \log I_e \rangle$ and $\log \sigma$ of the clusters of galaxies determine the fundamental plane (FP) in the near infrared: $\log R_e = 0.98(\pm 0.06)\ \log \sigma - 0.56(\pm 0.04)\langle \log \langle I_e \rangle \rangle + 3.57(\pm 0.07)$, which can be used to determine the distances of the galaxy systems. The root-mean-square deviation of the FP zero-point is 0.07, which corresponds to an error of 16% in determining the distance of the group or cluster of galaxies. For the first time we have measured the peculiar velocities of the superclusters of galaxies. The mean peculiar velocity of the 5 superclusters of galaxies relative to the CMB is $+75 \pm 360$ km/s.

Keywords: galaxies: groups and clusters: distances and redshifts; cosmology: large-scale structure of universe

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1 Introduction

The gravitationally bound systems — globular clusters of stars, galaxies, clusters of galaxies — obey the virial theorem in the form $M \propto R\sigma^2$, have similar relationships between parameters, for example, the fundamental plane. The FP is the empirical relationship between three observable properties of early-type galaxies: physical size (R), radial velocity dispersion along the line of sight (σ), and surface brightness. For the first time, the FP of galaxy clusters themselves has been constructed using photometric observational properties for a sample of 16 rich galaxy clusters ($z < 0.2$) (Schaeffer et al. 1993).

The aim of this work is to construct a FP between the parameters of 172 groups and clusters of galaxies that have redshifts in the range $0.012 < z < 0.10$ and the radial velocity dispersions 200 km/s $< \sigma <$ 1100 km/s. The properties we determine, L_K ($\langle \log I_e \rangle$), σ, R_e (found from $N_{\rm tot}/2$) and the relations between them (the fundamental plane), give us the opportunity to measure the relative distances of galaxy clusters in superclusters, the galaxy superclusters themselves, and to find the standard logarithmic scatter of groups and clusters of galaxies on the Hubble diagram. The work was carried out by us using data from the catalogs SDSS, 2MASS XSC, NED.

2 Method

In the paper Kopylova & Kopylov (2016) we showed that in galaxy clusters it is possible to find an effective radius that contains half of the galaxy halos, in order to construct a common FP for both poor groups and rich galaxy clusters. To do this, for groups/clusters of galaxies, we determine the splashback radius $R_{\rm sp}$, following the methodology outlined in Kopylova & Kopylov (2016), and find the number of galaxies within it, corrected for the background (determined by the slope of the straight line). The determination of the total luminosity of a galaxy cluster using the luminosity function (LF) within a selected radius consists of two steps, described in detail in Kopylova & Kopylov (2024): first the LF is normalised to the observed number of galaxies, then it is extrapolated into the region of faint magnitudes to a selected limit.

Figure 1 shows the received FP of our entire sample of 172 groups and clusters of galaxies, and individual members of each galaxy supercluster are highlighted with large circles. Red circles correspond to groups of galaxies, blue ones to clusters of galaxies. The line shows the regression relation obtained from galaxy clusters with $\sigma > 400$ km/s. It looks like: $\log R_e = 0.98(\pm0.06) \log \sigma - 0.56(\pm0.04)\langle \log I_e \rangle + 3.57(\pm0.07)$.

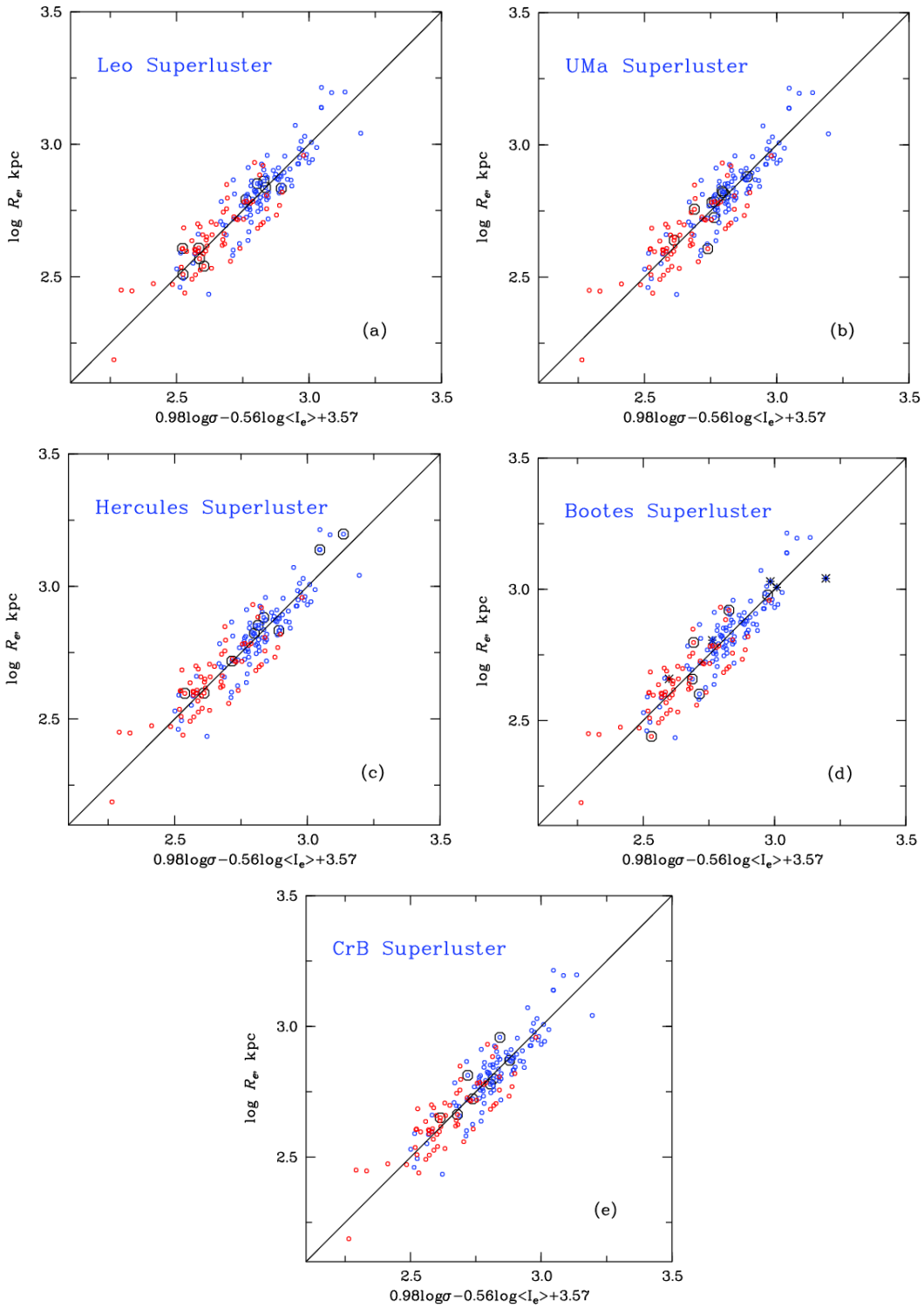

Fig. 1. Fundamental plane of 172 groups and clusters of galaxies in the IR region along the long axis, $\log R_e$. Members of the superclusters of galaxies Leo, Ursa Major, Hercules, Bootes, Corona Borealis are circled.

This ratio has a small scatter and is suitable for measuring the relative distances of galaxy systems when $\log R_e$ is measured in arcseconds. Thit means that the zero point of the FP changes depending on the distance to the galaxy systems.

In practice, the difference between the cluster zero point $\gamma_{\rm cl}$ and the overall mean zero point γ is used to calculate photometric redshifts: $z_{\rm FP} = z_{\rm CMB} \times 10^{(\langle\gamma\rangle - \gamma_{\rm cl})}$. Then the peculiar velocities of the galaxy clusters in the comoving system are equal to the difference between the spectroscopic and photometric redshifts: $V_{\rm pec} = c\,(z_{\rm CMB} - z_{\rm FP})/(1 + z_{\rm FP})$. We have found that the average peculiar velocity of galaxy superclusters relative to the CMB is $V_{\rm pec} = +75 \pm 360$ km/s.

3 Results

In this work we constructed the fundamental plane of 172 clusters and groups of galaxies and show that the FP is consistent with the results of other authors using other methods (Schaeffer et al. 1993). The main results of this study are given below: the general FP of 172 groups and clusters of galaxies in the K-band has the form: $L_K = R_e^{0.64\pm0.08}\sigma^{1.45\pm0.06}$ with $rms = 0.13$.
For the first time, the FPs of members of 5 superclusters of galaxies (Leo, Hercules, Ursa Major, Bootes, Corona Borealis) have been constructed, and the relative distances and peculiar velocities of the groups/clusters of galaxies have been determined.

References

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